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A Sedimentation Study of the Green River Irrigation Canal, Green River, Utah

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A SEDIMENTATION STUDY OF THE GREEN RIVER IRRIGATION CANAL,

GREEN RIVER, UTAH

by

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ABSTRACT

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Utah State University, 2006

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This sedimentation study of the Green River irrigation canal provides the Green River Canal Company (GRCC) with a detailed aerial map of the Green River irrigation canal system to allow operators to quickly and accurately locate canal structures. Also, an Excel spreadsheet accounting model was created which provides the GRCC with the ability to determine where sedimentation likely occurs throughout the canal under given conditions. This model must be operated within set guidelines to provide reliable results and should be calibrated for increased accuracy. It was determined that with no irrigation (i.e., with no canal structures open except for the final return) a minimum flow rate of sixty-three cubic feet per second is needed to prevent sedimentation throughout the canal. Therefore, a flow rate above sixty-three cubic feet per second is needed for any irrigation along the canal in order to prevent sedimentation.

(106 pages)

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Jan Michael Miller

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LIST OF SYMBOLS

Symbol

A	Full cross-sectional area
A_o	Orifice area
c	Constant value for circular CMP with headwall
C_d	Discharge coefficient
D	Orifice diameter
g	Acceleration due to gravity
H	Measured head from water surface to center of orifice
HW_i	Headwater depth
Ku	Constant value equals unity for English units
Q	Flow rate
S	Slope
Y	Constant value for circular CMP with headwall

CHAPTER I

INTRODUCTION

Rivers and streams flowing in natural alluvial channels often contain a large amount of suspended silt particles. The velocity of the flowing water plays a very important role in determining whether the suspended silt will settle and collect along the bed of the channel. Decreasing the velocity of the water in the channel or increasing the concentration of suspended silt will increase the amount of sedimentation which occurs. This sedimentation process is a major concern of overland flow irrigation systems, causing problems of reduced conveyance capacity and blockage of turnouts and other irrigation structures. The frequent maintenance required to mitigate these problems results in a significant cost to irrigation system owners and users.

The Green River Canal Company (GRCC) was formed in the 1880's to service the needs of farmers in the surrounding area of Green River City, located in southeastern Utah. At this time the GRCC built an 8½ mile canal including a 2,500 foot-long section called the raceway, which is an unlined channel designed to carry irrigation water diverted from the Green River at low velocity to allow silt to settle out before entering the main irrigation canal. In the early 1990's alterations were made to an existing pumping station situated at the end of the raceway and near the inlet to the main irrigation canal, resulting in increased velocity through the raceway which decreased the amount of silt being removed from the water in the raceway. As water carrying high concentrations of suspended silt enters the irrigation canal, lower velocity in the canal results in sedimentation problems which increases annual GRCC maintenance costs. Because it is not feasible for the GRCC to pay for the necessary annual maintenance costs incurred by sediment depositing throughout their irrigation canal, this study was initiated to determine the possibility of preventing future sedimentation.

There are five objectives which this study sought to accomplish for the GRCC. The first was to provide information from previous research regarding the sediment material found in the Green River canal as a result of the sedimentation process. This includes grain size distribution and a classification of the types of soils present, and the minimum velocity required to maintain suspension of the silt particles entering the irrigation canal. The second objective was to create a detailed map of the Green River irrigation canal including the location of all turnouts, returns, and check gates to aid the GRCC in locating, governing, and maintaining the irrigation structures in their system. The third objective was to create a spreadsheet accounting model which describes the operating conditions of the canal and allows canal operators to minimize sedimentation by predicting conditions for which it will likely occur. The fourth objective was to provide the GRCC with a set of operational guidelines for the Green River irrigation canal, and which also describes how the Green River canal model functions. The final objective was to provide the GRCC with recommendations for canal operation in order to prevent sedimentation.

CHAPTER II

LITERATURE REVIEW

A review of the material related to sedimentation in irrigation canals produced several sources that deal with suspended sediment transport. One particular source written by Néstor J. Méndez (1998) explains that siltation problems frequently occur in irrigation canals, clogging turnouts and reducing conveyance capacity and ultimately requiring high annual investments for rehabilitation in order to maintain their functionality. He later states that a "key problem for operating an irrigation canal is to determine the flow conditions for which the water requirement is met with minimum deposition" (Méndez 1998). His research includes the development of a mathematical model to describe sediment transport in irrigation canals and uses one of the fundamental water flow equations, the continuity equation. This equation states that the discharge into and out of a control section are equal and the discharge past a section is equal to the product of the average velocity and the cross sectional area (Prasuhn 1992).

Another resource which deals with the prevention of sedimentation in irrigation canals indicates that the factors influencing the sedimentation process include variation of channel bed width, channel depth, and mean velocity of the water in the channel. The mean velocity is obtained by measuring the cross-sectional area of the channel where discharge is at a known "full supply" which is classified as somewhat greater than the average discharge and less than the flood discharge (Kennedy 1895).

Two articles describe the problem of aggrading and degrading irrigation channels and the three approaches which may be taken to avoid the problem (ASCE 1972). The first article explains that aggrading channel beds fill with sediment whereas degrading beds progressively lose bed or bank material, and that in either case the problem is an imbalance of the sediment load which must be restored by decreasing the sediment inflow, increasing transport capacity, or using a combination of the two.

In the second article, the three approaches outlined for preventing sedimentation are to allow only water into the irrigation channel while returning sediment back to the silt-laden water source; to design the canal system hydraulically to transport the suspended silt onto land with a minimum of sediment deposited in the canal; and to design the headworks of the canal such that as little silt as possible is allowed to enter the canal and at the same time employ the least expensive method for sediment removal. This article further explains the difficulty of conveying sediment-laden water through an irrigation canal system and states that to maintain the suspension condition of silt entering the canal the velocity throughout the canal must be maintained at or above that required to maintain suspension. Also, this article explains that creating checks in the canal at lower flow rates in order to increase the water level required to provide gravity flow of water through canal turnout structures will reduce velocities and result in sediment deposition between these checks or barriers (ASCE 1972).

Similar conditions exist throughout the Green River irrigation canal. Portions of the canal are noticeably aggrading, several turnout structures are either partially or entirely covered with sediment material, and check gates are used to increase water level to maintain a bank full condition at low flow rates during the middle of the irrigation season, resulting in sedimentation. It has been determined that the most economical solution to prevent sedimentation in the Green River irrigation canal is to determine the required minimum velocity to maintain suspension of silt particles entering the canal and evaluate how to achieve this velocity throughout the canal.

Prior to this study, research was conducted on sediment samples collected from the Green River irrigation canal by Michael Stoeber (2005). A grain size distribution analysis was performed on these samples using the method outlined in Bowles (1992). The results of Stoeber's analysis are presented in chapter three of this thesis. This study will build upon Stoeber's previous research by using its findings to create a model which defines canal operating conditions needed to prevent sedimentation in the Green River irrigation canal.

CHAPTER III

STUDY PROCEDURES

This chapter describes the procedures used to accomplish the five objectives set forth in this study. These objectives include an analysis of the sediment material present in the Green River irrigation canal and the determination of the minimum required velocity to maintain suspension of the silt particles entering the canal; the technology and procedures employed to create an aerial map of the canal; a description of the Green River canal model; operational parameters for the model and an explanation of how it functions; and recommendations for operating the canal in order to prevent sedimentation and limit sedimentation at lower flow rates during the irrigation season.

ANALYSIS OF SEDIMENT MATERIAL AND MINIMUM REQUIRED VELOCITY

This section contains the results of research conducted prior to this study by Michael Stoeber at Utah State University (2005). Stoeber's findings provide the foundation on which the third objective of this study, the creation of the Green River irrigation canal model, is set up.

Two different sediment samples were collected for analysis by Stoeber, one from the upper end of the Green River irrigation canal and the other from the lower end, which consisted of a very fine sand and clayey soil type, respectively. A mechanical sieve analysis was conducted to determine the range of grain sizes for the very fine sand and hydrometer tests were conducted on 50 grams of both the clayey type sample and 50 grams of the sandy type sample which passed through the number 40 sieve.

A flume study was used to determine the "critical grain entrainment velocity" or minimum required velocity to maintain suspension of the silt particles by introducing silt at the surface of flowing water in the flume and visually noting the velocity at which the silt particles were carried through the flume without the occurrence of sedimentation. The velocity profile in the flume was then measured.

From the grain size analysis Stoeber determined the D_{16}, D_{50}, D_{65}, D_{85}, and D_{90} to be 0.05 mm, 0.12 mm, 0.16 mm, 0.18 mm, and 0.19 mm, respectively for the non-cohesive or sandy type sample. Using the ASCE sediment size classification, Stoeber classified the non-cohesive soil as very fine sand. Stoeber found in his comparison with flume studies that Dingman's (1984) method adequately expressed the average vertical velocity "critical grain entrainment velocity" in the canal required to transport the non-cohesive silt particles. This velocity was found to be 1.14 feet per second and corresponds to a grain diameter of 0.25 millimeters, which is greater than nearly all of the sediment sizes sampled from the Green River irrigation canal and corresponds approximately to the D_{95} of the very fine sand.

Stoeber's analysis of the cohesive soils sampled from the canal determined the D_{16}, D_{50}, D_{65}, D_{85}, and D_{90} to be 0.001 mm, 0.005 mm, 0.009 mm, 0.025 mm, and 0.03 mm, respectively. This soil type was classified as medium silty clay using the ASCE sediment size classification. Stoeber reports that the critical grain entrainment for the cohesive soils is at or near a bed velocity of 0.9 feet per second.

Based on this analysis, a minimum required velocity of 1.14 feet per second is recommended to maintain suspension of the silt material entering the Green River irrigation canal, including the cohesive and non-cohesive soil types, assuming this material is similar to the sediment samples studied. Also, based on Stoeber's research, this minimum required velocity to prevent sedimentation throughout the canal is conservative since it corresponds not to the average particle size, or D_{50}, but rather to a larger particle size, D_{95}, of the very fine sand. It is possible to limit the sedimentation throughout the canal to a minor amount by maintaining a velocity above 0.9 feet per second. Below a velocity of 0.9 feet per second, significant sedimentation will occur in the canal.

AERIAL MAP OF THE GREEN RIVER IRRIGATION CANAL

The second objective of this study was to provide the Green River Canal Company with a detailed map of their system to allow them to quickly and accurately identify the location of all their turnout structures, which is useful for operation and maintenance procedures.

To provide an accurate location of turnout structures along the canal, global positioning system (GPS) technology was used to collect the position of all the canal structures represented on the aerial map. The aerial map was created using ESRI's ArcGIS 9, ArcMap software. Each structure was stored as a data point using a handheld GPS unit in Universal Transverse Mercator (UTM) coordinates and then transferred as a database file, using the Microsoft Excel spreadsheet program, to the ArcGIS 9, ArcMap program in order to create an accurate aerial map of the entire Green River irrigation canal. A visual inspection insured that each point entered into the GIS aerial map was located in its proper position with respect to the canal and the orthographic photos shown on the map.

Each point on the aerial map indicates the location of a canal structure including turnouts, residential turnouts, returns, and check gates (stop logs). Each structure is labeled with a callout box; those structures located on the West side of the canal are shown on the map on the left side of the canal and structures located on the East side of the canal are shown on the map on the right side of the canal, except for turnouts 59-62 which are noted on the map. The following system is used to represent the canal and the different types of canal structures shown on the map:

- A blue line represents the flow path of the irrigation canal beginning at the inlet of the canal and running south to the point where the canal joins with the Green River
- Orange dots represent turnouts (from T1 to T62)
- Green triangles represent residential turnouts (from RT1 to RT34), these are typically small residential pumps used for irrigating lawns and gardens
- Yellow squares represent return structures where flow can return from the irrigation canal back to the Green River (from R1 to R7)
- Red hexagons represent check gates (from G1 to G5)

The Green River irrigation canal aerial map is shown in Fig. 1.

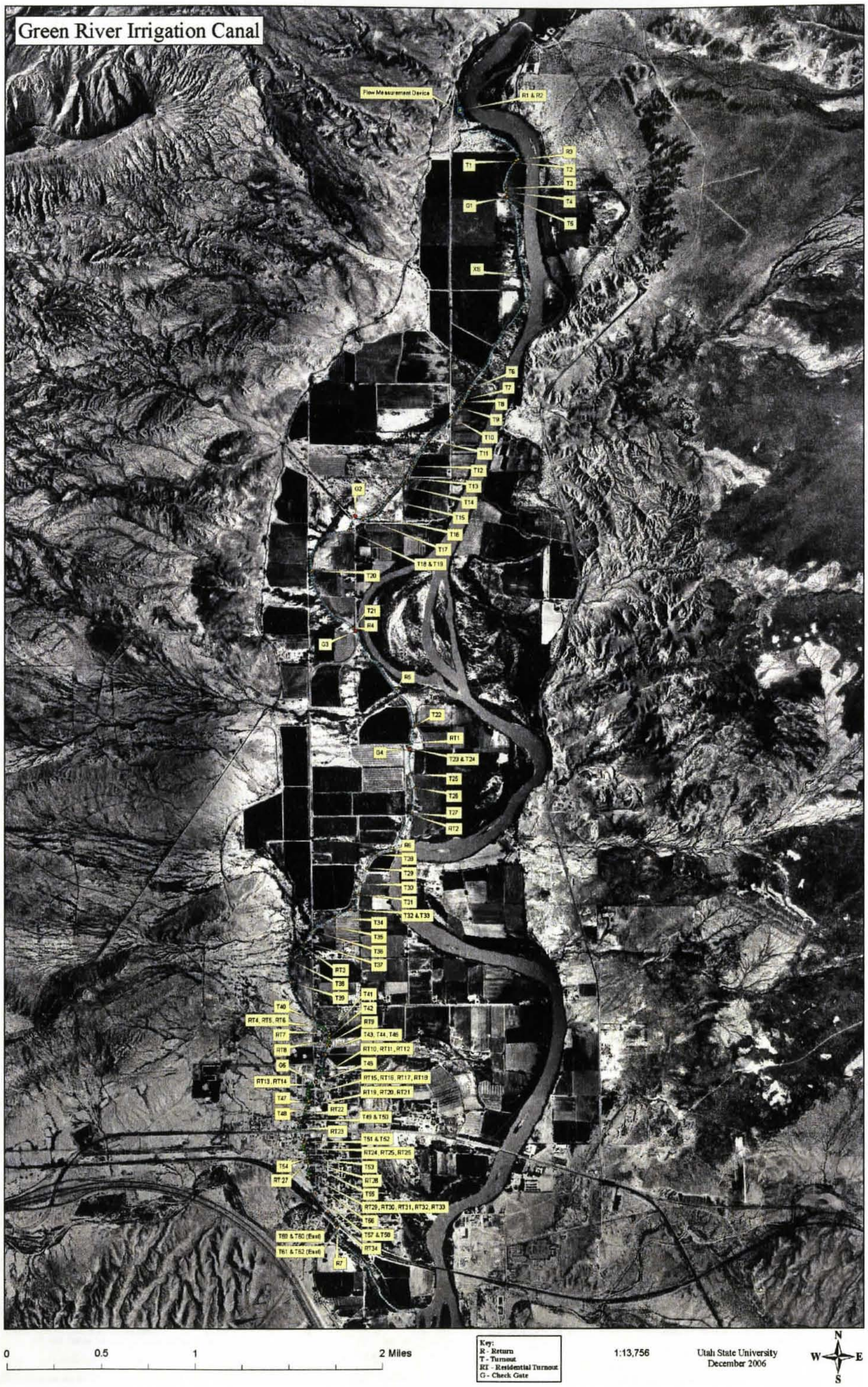

Fig. 1. Aerial map of the Green River irrigation canal

A full size copy of this aerial map is provided to the GRCC for their use. Nearly all of the canal structures have a corresponding photograph which is included in the Appendix.

GREEN RIVER IRRIGATION CANAL MODEL

In fulfillment of the third objective of this study, the Green River irrigation canal model was completed using the Microsoft Excel spreadsheet program. Microsoft Excel is needed in order to run the program on a personal computer and the model requires approximately 7.77MB (7.77 megabytes) of computer memory (disk space). The rest of this section will be devoted to describing the three steps involved in using the model. An example of how the model appears in Microsoft Excel is shown in Fig. 2.

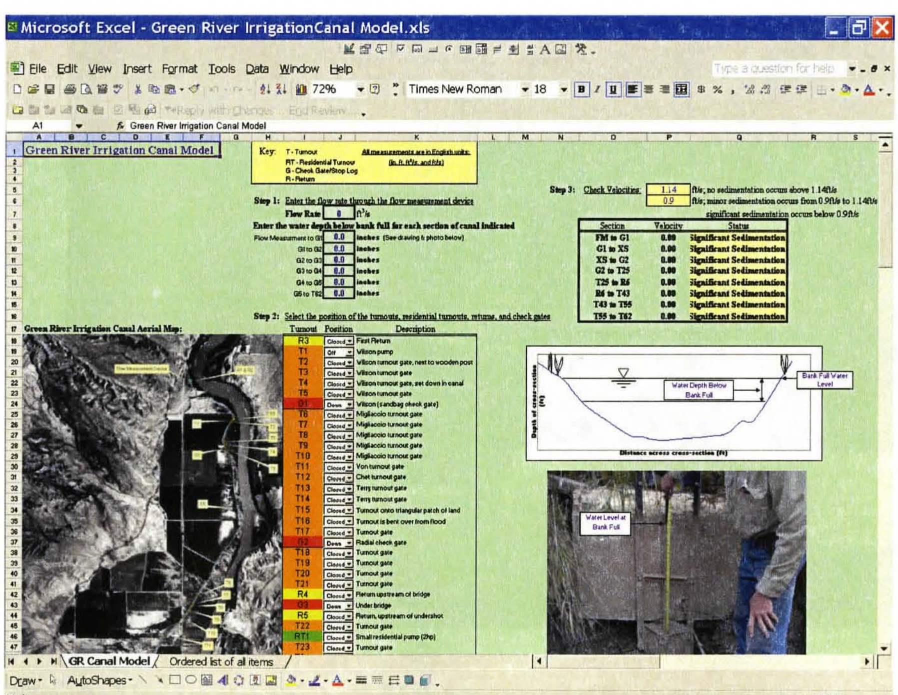

Fig. 2. The Green River irrigation canal model as it appears in Excel

This example depicts only a portion of the entire model which may be viewed in Excel by using the scroll bars located along the bottom and right side of the window as shown in Fig. 2. Figure 2 only displays those portions of the model which are necessary to explain the steps for using the model. It is noted that all measurements entered in the model and displayed by the model are in English units (i.e., inches (in), feet (ft), feet per second (ft/s), and cubic feet per second (ft^3/s)). Also, the yellow box shown near the top of Fig. 2 displays a key which explains the meaning of the symbols used in the model.

The first step in using the model is shown as "Step 1:" in Fig. 2 and indicates that the model user must first input the flow rate measured inside the flow measurement device shown in the following Fig. 3. This measurement is taken in cubic feet per second.

Fig. 3. The upstream half of the concrete flow measurement device

In Fig. 3 the first two returns, R1 and R2 are shown on the upstream wingwalls of the flow measurement device. The flow measurement through this device must be taken just downstream of these two returns on the inside, or between the parallel walls of the flow measurement device, in order to avoid accounting for the flow removed from these two returns in the Green River irrigation canal model. This flow rate measurement is entered in the box to the right of the words “Flow Rate” shown in Fig. 2 by clicking in the box, typing the number, and pressing the enter key. In Fig. 2, this number is shown as zero.

Next, the amount of depth below bank full, measured in inches, is entered in the boxes located just underneath the box where the flow rate was entered. Due to the fact that check gates are used during low flow conditions to artificially raise the level of the water in the canal, the depth below bank full may be entered in the model for the sections between each gate structure (i.e., between the flow measurement device and gate 1; between gate 1 and gate 2; between gate 2 and gate 3; between gate 3 and gate 4; between gate 4 and gate 5; and between gate 5 and turnout 62).

The “bank full” condition refers to the water level when the canal is at normal operating or full capacity and was measured from the observed high water line in the canal. The bank full condition is the typical operating condition needed in order to deliver the water from the canal to the users through their turnout structures by gravity flow. Figure 4 displays an example of how the bank full condition was measured and is also included in the model as a reference for measuring the depth below bank full.

Fig. 4. Measuring the water depth above a turnout at bank full condition

The bank full mark is indicated by the muddy line on the turnout gate. In cases where the bank full condition was not clearly marked on the turnout structure, the bank full condition was measured from the top of the turnout structure to just below the growth of vegetation along the canal. An example of this is indicated in Fig. 5.

Fig. 5. Bank full condition shown just below the vegetation growth

The second step in using the model, indicated in Fig. 2 as "Step 2:" is to select the position of the turnouts, residential turnouts, returns, and check gates along the canal. Each canal structure is listed and highlighted with its corresponding color as previously explained in the section "Aerial map of the green river irrigation canal." A description is listed to the right of each structure. The Green River irrigation canal aerial map is shown in the model to aid the user in locating and determining the position of the structures along the canal. There is another tab in the model labeled "Ordered list of all items" located on the bottom left of the Excel window (see Fig. 2) which may be accessed by clicking on the tab. This sheet includes a list of all the canal structures along the flow path of the canal and a list of the corresponding photo number which may be helpful for identifying a particular canal structure. Each of the canal photos are listed in the Appendix. To select the position of a structure whether open or closed, on or off, up or down, the user must click on the desired drop down box and select the structure's position. This procedure is shown in Fig. 6.

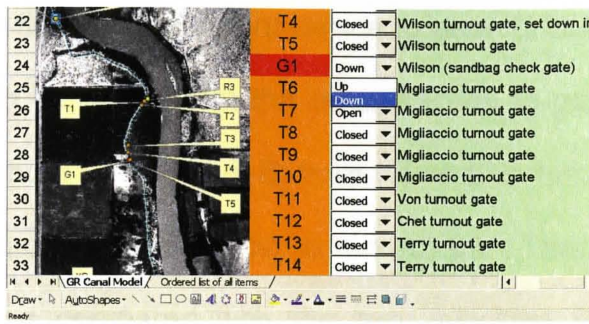

Fig. 6. Selecting the position of gate 1 (G1)

After all of the canal structures have been checked and their positions have been selected, the user may now move to step three and determine if and where sedimentation is likely occurring throughout the canal. The table shown in Fig. 7 represents the table listed under step three in the model.

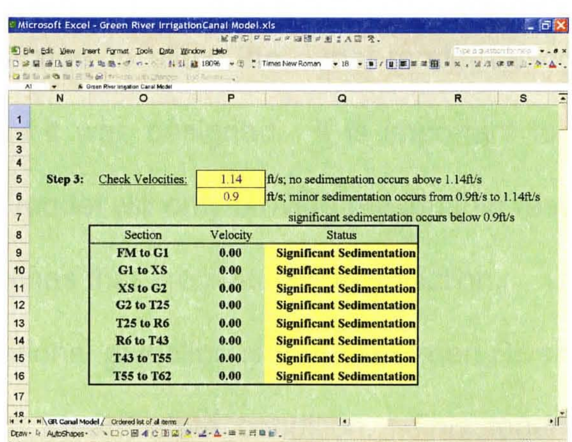

Fig. 7. Step three in the Green River irrigation canal model

This table (see Fig. 7) indicates the sections of the canal where sedimentation may or may not occur given the conditions entered in steps one and two. The model checks the velocity between the sections shown in Fig. 7, which are: from the flow measurement device to gate 1; from gate1 to the cross section indicated on the map; from the cross section to gate 2; from gate 2 to turnout 25; from turnout 25 to return 6; from return 6 to turnout 43; from turnout 43 to turnout 55; and from turnout 55 to turnout 62. The minimum velocity in each section is then compared with the two velocities shown in the yellow highlighted boxes (1.14ft/s and 0.9ft/s) to determine whether sedimentation is likely to occur. For the example as shown in Fig. 7, the flow rate was entered as zero so the velocity is also shown as zero and the corresponding "Significant Sedimentation" status is displayed.

OPERATIONAL GUIDELINES AND HOW THE CANAL MODEL FUNCTIONS

There are certain parameters which govern how the Green River irrigation canal should be operated to allow the canal model described in the previous section to function as it was designed. It is important to note that the Green River irrigation canal model will only provide reasonable results when used within the operational guidelines that are stated in this section.

The first operational guideline is that the Green River irrigation canal must be operated under a steady-state condition. This means that there are no changes in water depth throughout the canal at any given location with respect to time. This condition may be verified by measuring the water depth at several locations in each section of the canal (i.e., between each check gate) after waiting a period of at least twelve hours from the last change in operation (e.g., opening/closing turnouts or returns, or lowering/raising check gates). Twelve hours was indicated by the GRCC as the minimum amount of travel time it takes for water to enter the canal inlet and exit the canal through return 7. These measurements should be checked more than once and there should be no change in the water depths between measurements to ensure that the steady-state condition exists. At lower flow rates, when check gates are used, it may be necessary to wait more than twelve hours for the flow in the canal to reach the steady-state condition.

The Green River irrigation canal model operates under the assumption that the water level in the canal is at bank full condition as indicated by the high water mark along the canal. Examples of measuring this mark are shown in Figs. 4 and 5. If the measured water level in the canal drops below the bank full condition in any section, where a section is defined as a portion of the canal between check gates, then this drop must be measured and input in the canal model in the proper input box to account for this decrease in water deliverance.

Accurate flow rate is an essential input in the Green River irrigation canal model and care must be taken when recording this measurement through the flow measurement device shown in Fig. 3 and located just downstream of the canal inlet. Flow rate must be measured inside the flow measurement device, downstream of returns 1 and 2 located on the upstream wingwalls of the device. The United States Bureau of Reclamation (USBR) recommends two separate flow rate measurement methods for open channel flow that apply in this situation. These two methods may be found in their Water Measurement Manual (USBR 2001), which may be found online by searching for the USBR Water Measurement Manual. The first is the "float method" which is located in the USBR Water Measurement Manual in chapter 13, section 10. Errors associated with this method may be as much as ten to twenty percent (Merkley 2006). The second method, which is more accurate than the first, is the current metering method and may be found in the USBR Water Measurement Manual in chapter 10, sections 10-13.

Each canal structure (turnout, residential turnout, and return) is assumed to be in a fully-open or fully-closed position for the canal model to work properly. Also, the inlet of each structure must be submerged. In the event that the water level drops below the inlet to a canal structure the model assumes that zero flow is moving through the structure. When using the Green River irrigation canal model, the user must monitor each pump and make sure that if the water level drops below the point at which a particular pump may draw water, the user selects the "Off" position for that particular pump in the model.

The Green River irrigation canal model does not take into account any water that may be entering the canal from any other source than through the canal inlet. This would include any water runoff which may be draining into the canal. The reason for this is that such addition in water flow rate could not be accounted for by measuring the flow rate inside the flow measurement device. Similarly, the model does not take into account any water that may be exiting the canal from any source other than through those structures listed in the canal model.

Any additions to structures not already listed in the canal model, including turnouts, residential turnouts, returns or check gates are not represented in the existing model and such additions will not allow the model to calculate reliable results. The Green River irrigation canal model is a tool which provides an approximation of true existing conditions and may provide reliable results as long as the previously mentioned conditions and guidelines are maintained.

The following is a breakdown of how the Green River irrigation canal model calculates the velocity used to check whether sedimentation likely occurs in the canal under given conditions. First, the model uses the flow rate entered from the measurement taken inside the flow measurement device and proceeds from that point to check the position of each canal structure, whether it is on or off, open or closed. Each structure is checked in the order it is located along the flow path of the canal. When a structure is designated as open or on in the model, the flow through the structure is calculated and subtracted from the amount of flow through the canal at the structure.

The velocity is then calculated at each canal structure, and between each section of the canal indicated in step three of the model (see Fig. 7), and the lowest velocity in each section is then checked against the two velocities previously mentioned at the end of the "sediment material and minimum required velocity analysis" section in this thesis to determine whether sedimentation occurs in the canal. If the calculated velocity is greater than 1.14 feet per second then the “No Sedimentation” status is displayed. For a calculated velocity between 1.14 feet per second and 0.9 feet per second the model displays the “Minor Sedimentation” status, and if the calculated velocity is less than 0.9 feet per second the model displays the “Significant Sedimentation” status.

The velocity through each open structure (turnout or return gate) is calculated based on the orifice equation with inlet control (Jones 1953) as shown in the following Eq. 1.

$$Q = C_d A_o \sqrt{2gH} \tag{1}$$

where Q is the flow rate through the orifice measured in cubic feet per second, C_d is the orifice discharge coefficient (0.61 is the typical value which is used in this case), A_o is the area of the opening of the structure, g is the acceleration due to gravity, and H is the head of water measured from the water surface to the center of the orifice of the structure.

The equation for a submerged culvert under inlet control may be used as a check on the accuracy of the orifice equation employed in the canal model to calculate flow rate through submerged canal structures. Example calculation results are shown below to compare the accuracy of the orifice equation with the equation for a submerged culvert under inlet control. The following equation is taken from the FWHA’s HDS-5 manual (2001).

$$\frac{HW_i}{D} = c\left[\frac{K_u Q}{AD^{0.5}}\right]^2 + Y - 0.5S^2 \tag{2}$$

where HW_i is the headwater depth above the inlet control section invert, D is the interior height of the culvert barrel, Q is the flow rate through the culvert, A is the full cross-sectional area of the culvert barrel, *S* is the culvert barrel slope, *c*, *Ku*, and *Y* are constants which depend on the shape and material of the culvert. Equation 2 may be rearranged to solve for the flow rate, *Q*, through the culvert orifice.

$$Q = \frac{AD^{0.5}}{K_u}\left[\frac{\frac{HW_i}{D} - Y + 0.5S}{c}\right]^{1/2} \tag{3}$$

In order to compare Eqs. 1 and 3, the following information is used: C_d = 0.61, D = 1ft, A_o = 0.785ft^2, S = 0.001 and is assumed to be nearly horizontal, g = 32.2ft/s^2, H = 1.5ft, HW_i = 2ft, K_u = 1.0 for English units, and for a circular CMP culvert with a headwall c = 0.0379 and Y = 0.69. Using Eq. 1 to calculate the flow rate yields $Q = 4.71ft^3/s$. A flow rate of $Q = 4.62ft^3/s$ is calculated using Eq. 3. The flow rate calculated using the orifice equation is very close to the flow rate calculated using the culvert equation therefore; using the orifice equation is an adequate method for calculating flow rates through submerged canal structures in the Green River irrigation canal model.

Except for the two pumps along the canal used to irrigate the high school and the ballpark, the size of the pumps used for residential irrigation were small (about 2 horsepower). The amount of water drawn from each pump was approximated using information gathered from Green River City and from a small pump manufacturer (from Craftsman pump). The flow rate through each pump was input directly in the canal model and is subtracted from the flow rate in the canal at each pump when a particular pump is designated as “On” in the model.

Eight representative cross-sectional areas were measured along the canal for use in calculating the velocity throughout the canal with a given flow rate. These cross sectional areas were measured using two measuring rods, one was stretched across the top of the canal at the "bank full" water mark and the other was used to measure depth from the canal bed to the water surface at bank full condition (see Fig. 121 in the Appendix). A depth measurement was recorded along each cross section in increments of one foot in order to calculate the cross-sectional area. Using a measured cross-sectional area and calculated flow rate along the flow path of the canal, the velocity throughout the canal is calculated in the canal model using the continuity equation where velocity equals flow rate divided by cross-sectional area. If water is flowing below bank full in a section of the canal between two check gates, the depth below bank full entered in the canal model in "Step 1:" is subtracted from the cross-sectional area of the canal in that particular section in order to account for the difference in water flow rate.

The calculated velocities throughout sections of the canal are then compared with the minimum required velocity to prevent sedimentation. The method for dividing up sections along the canal was selected to reflect changes in cross-sectional area throughout the canal, areas where sedimentation has been a problem in the past, and sections of canal with similar cross-sectional area that are divided into shorter segments (e.g., the division between the last two sections). The model looks at the range of calculated values for velocity in each section and compares the lowest value with 1.14 and 0.9 feet per second and displays the corresponding status for each section as previously mentioned.

RECOMMENDATIONS

The following is a list of recommendations which will aid canal operators when using the Green River irrigation canal model to prevent the occurrence of future sedimentation. This list applies to and is based on the canal model as it exists when delivered to the Green River Canal Company.

It is very important to check every input to the canal model to ensure that the model displays the correct operating conditions that the user wants to evaluate. Each measurement should also be checked carefully for accuracy. It is recommended that canal operators wait a minimum of twelve hours after making any modification to the operating conditions of the canal to make certain that water in the canal is flowing under the steady-state condition. It is also recommended that the steady-state condition be verified by measuring the water depth at multiple locations in each section (i.e., between each check gate) at least twice for a certain period of time. Waiting a greater amount of time between each measurement will allow the operator to determine with greater certainty that the canal is operating under the steady-state condition. The flow rate inside the flow measurement device may be measured after the steady-state condition has been established throughout the canal and should be taken using the current metering procedure for greater accuracy.

Any debris that has accumulated throughout the canal and sediment that has deposited in front of or inside canal structures should be removed prior to operation including sections of bank material that have caved in. Any canal structures that are not in use should be closed to prevent unnecessary loss of flow from the canal. Based on previous research, the minimum required velocity to prevent sedimentation throughout the canal is 1.14 feet per second. In order to prevent sedimentation throughout the canal, the canal should not be operated with velocities lower than 1.14 feet per second.

The Green River irrigation canal model must be calibrated in order to provide the most accurate results. This may be done by measuring the accurate flow rates from each canal structure in the fully-open position using the current metering method where applicable (see chapter V of this thesis). Pump flow rates should also be calibrated to correct for any differences in the flow rate estimated and used in the canal model.

After using the Green River irrigation canal model to identify a few of the key operational conditions, the following limits were determined. It was indicated by the GRCC that the final return, return 7, is always open. With return 7 fully-open and all other canal structures either closed or off (i.e., with no irrigation), it was found that a flow rate of 63 cubic feet per second must be flowing through the flow measurement device to prevent the occurrence of sedimentation. Figure 8 displays an example of the model to demonstrate how this conclusion was reached.

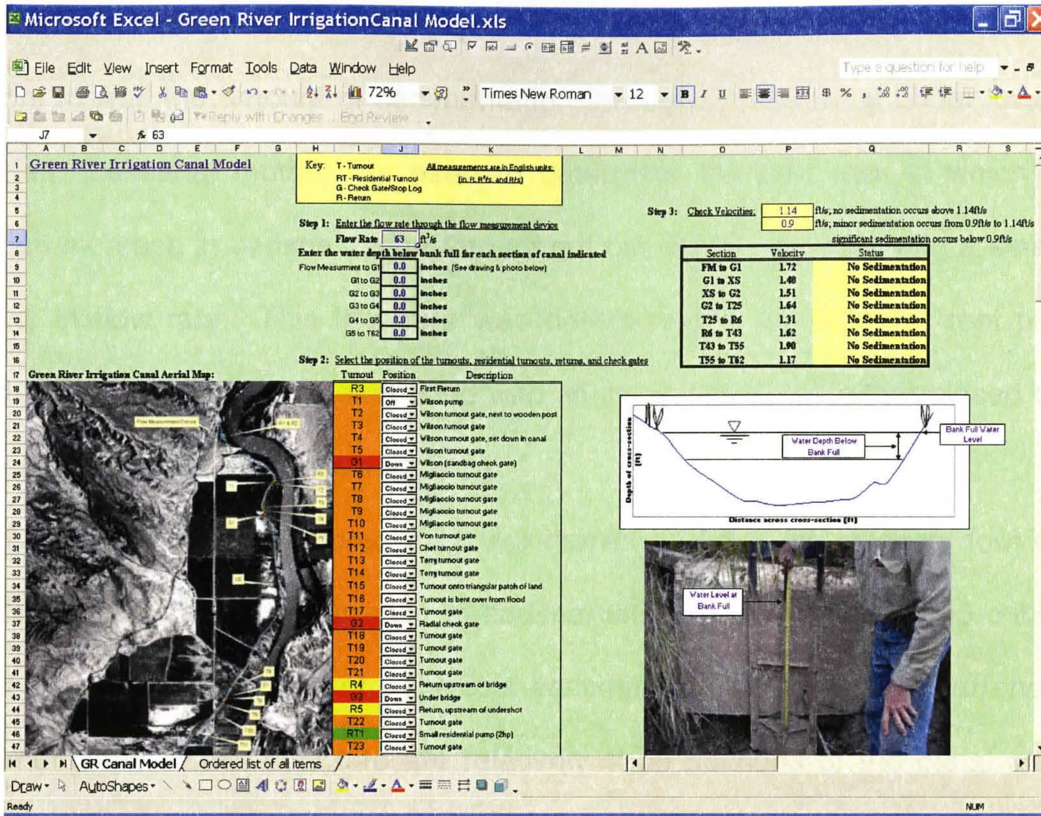

Fig. 8. The canal model indicates that with no irrigation a flow rate of 63 cubic feet per second is required to prevent sedimentation throughout the canal

At a flow rate of 62 cubic feet per second with no irrigation and all structures closed except for return 7, minor sedimentation occurs at the very end of the canal from return 7 to turnout 62. Under similar operating conditions, the canal model indicates that minor sedimentation begins to occur in more than one section of the canal just below a flow rate of 55 cubic feet per second. Also, without irrigation and only return 7 open, sedimentation occurs within each section of the canal with a flow rate just less than 38 cubic feet per second.

The Green River irrigation canal is often operated at lower flow rates during the irrigation season which means that complete prevention of sedimentation throughout the canal is not possible. In order to aid canal operators to limit the amount of sedimentation throughout the canal under lower flow rates, the canal model was used to determine the flow rate at which a significant increase in sedimentation throughout the canal will occur with a small decrease in flow rate. This flow rate was determined to be 45 cubic feet per second. This flow rate was determined with all canal structures either closed or off except return 7 (i.e., without irrigation).

Of all eight canal sections which are monitored for sedimentation, four of the sections indicate the occurrence of sedimentation at a flow rate of 45 cubic feet per second and four do not. The four sections that indicate the occurrence of sedimentation at this flow rate are relatively short sections of the canal and have larger cross-sectional areas where sedimentation would likely occur first. Therefore, it is recommended that when operating the canal at or below 45 cubic feet per second, the number of canal structures that are opened should be kept to a minimum in order to limit sedimentation throughout the canal.

A limitation of this study is the use of eight representative cross sections to calculate velocity throughout the canal. It is recommended that additional cross-sectional areas be measured along the canal and that this data be incorporated into the canal model to increase its accuracy. Also, an assumption was made in this study that all canal structures are operating under inlet control. Further analysis should be conducted to determine whether canal structures are operating under inlet or outlet control to determine the most accurate flow rate through each structure.

CHAPTER IV

CONCLUSIONS

Each of the five objectives set forth in this study were completed for the Green River Canal Company (GRCC). Information was provided in this thesis from previous research regarding the sediment material found in the canal and the velocities required to prevent sedimentation and to limit significant sedimentation throughout the canal. A detailed aerial map of the Green River irrigation canal system was created to provide the GRCC the ability to quickly and accurately identify the location of all structures that exist along the canal. The following system was used for labeling the map to make it easier for the GRCC to identify canal structures. A blue line indicates the flow path of the canal from the canal inlet at the north end of the canal to the point that it joins with the Green River at the south end of the canal. Orange dots represent turnouts (T1 through T62), green triangles represent residential turnouts (RT1 through RT34), which are typically small residential pumps used for irrigating lawns and gardens. Yellow squares represent returns back to the Green River (R1 through R7), and red hexagons represent check gates (G1 through G5).

Using the minimum required velocity for suspension of silt material in the canal, a spreadsheet accounting model was created. This canal model allows operators to analyze existing operating conditions to determine where sedimentation is likely occurring and it provides operators the ability to predict where sedimentation will likely occur with given operational conditions. These conditions must be checked carefully before entering them in the canal model and the model will only provide reliable results when the canal is operated under steady-state conditions (i.e., no change in water depth at any given location along the canal with respect to time). The stated recommendations in chapter 3 of this thesis should be followed for the best use of the Green River irrigation canal model.

The Green River irrigation canal model must be calibrated using prescribed current metering procedures found in the USBR Water Measurement Manual to provide the most accurate results. Using the model as it exists when delivered to the GRCC (without calibration), it was found that with all canal structures closed (i.e., with no irrigation), except for return 7 which is always in the fully-open position, sedimentation is prevented at or above a flow rate of 63 cubic feet per second passing through the flow measurement device located just downstream of the canal inlet. Therefore, in order to be sure that sedimentation is prevented throughout the canal, any irrigation water taken from the canal would be added to the 63 cubic feet per second.

It was also determined that a flow rate of approximately 45 cubic feet per second without irrigation (i.e., with all canal structures closed except return 7) limits the significance of sedimentation occurring throughout the canal and that small decreases in flow rate below 45 cubic feet per second will significantly increase the occurrence of sedimentation throughout the canal. Therefore, at flow rates below 45 cubic feet per second, the number of canal structures that are open should be kept to a minimum in order to limit sedimentation throughout the canal.

It is noted that there are other alternatives for removing silt from the canal (e.g., using a sedimentation basin to allow the silt to settle out before entering the irrigation canal). However, this study only deals with determining the minimum velocity and corresponding flow rate needed throughout the canal to prevent sedimentation. It is also important to note that historically the raceway was used as a sedimentation basin which allowed the majority of the suspended silt in the water taken from the Green River to settle out before the water entered the Green River irrigation canal and that now the velocity in the raceway has significantly increased due to hydropower operation at the end of the raceway, just before the inlet to the irrigation canal. In June of 2006 the measured average velocity in the raceway was 2.75 feet per second and in October 2006 the measured velocity just upstream of the inlet gates to the raceway was 2.21 feet per second. Both of these measurements indicate that the raceway is not functioning as a sedimentation basin to remove suspended silt from the water before it enters the irrigation canal as it was designed.

Also, in conversation with the GRCC, it was mentioned that the majority of the sedimentation problem begins to occur in the middle of the irrigation season around mid July. At this time the flow rate entering the raceway is significantly decreased from the amount entering the raceway in spring and early summer. The difference in water level from the raceway to the Green River is greater at this time than in spring and early summer which allows the turbines located adjacent to the inlet of the irrigation canal to generate more hydropower. This not only reduces the amount of silt that is allowed to settle in the raceway because of the increased velocity throughout the raceway but also contributes to a greater sedimentation problem in the Green River irrigation canal because of the lower flow rate and lower velocities in the canal at this period in the irrigation season.

CHAPTER V

FUTURE RESEARCH

The most important future research that should be conducted is the calibration procedure of the Green River irrigation canal model. The USBR provides a reliable current metering procedure for measuring velocity and flow rate in open channel structures in their Water Measurement Manual found online. Because the Green River irrigation canal model calculates flow rates through canal structures in the fully-open position, the calibration of the model should be conducted with structures in the fully-open position. To provide the most accurate flow rate measurement through a particular canal structure, each structure should be analyzed to determine whether it is operating under inlet or outlet control. Additionally, each flow rate should be measured at the outlet of the structure using the current metering method. After determining the accurate flow rate through each canal structure, this flow rate measurement could then be entered directly in the canal model in the table labeled “Potential Flow (cfs),” in the highlighted column labeled "Q (cfs)," for the corresponding canal structure. The canal model will then calculate more accurately the velocity throughout the canal under given operational conditions, which will also more accurately predict the location where sedimentation is likely to occur.

Additional future research includes determining alternative methods to significantly reduce the concentration of silt in the canal (e.g., using a sedimentation basin and structures for sluicing the deposited sediment back to the Green River). The GRCC indicated that the return structures (R1 through R7) are used to remove deposited sediment throughout the canal by sluicing it through the returns back to the Green River. Therefore, a study may be conducted to determine the best operation of the return structures for sluicing sediment back to the Green River. A feasibility study may be conducted for the use of a piped system to supply irrigation water to Green River irrigation canal users.

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APPENDIX

LIST OF PHOTOS OF CANAL STRUCTURES IN ORDER OF FLOW PATH

Fig. 9. (Photo #1) "Eight gates," the inlet to the raceway which feeds the Green River irrigation canal, flow is from left to right

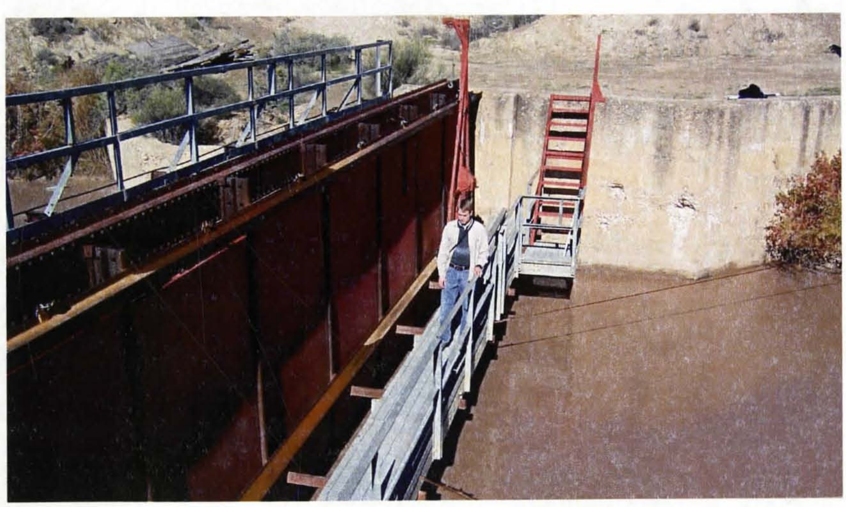

Fig. 10. (Photo #2) Inlet gates to the raceway, flow is from right to left

Fig. 11. (Photo #3) Green River irrigation canal inlet

Fig. 12. (Photo #4) Concrete flow measurement device and returns 1 & 2

Fig. 13. (Photo #5) Upstream section of flow measurement device

Fig. 14 (Photo #6) Return 3

Fig. 15. (Photo #7) Turnout 1

Fig. 16. (Photo #8) Turnout 2

Fig. 17. (Photo #9) Turnout 3

Fig.18. (Photo #10) Turnout 4

Fig. 19. (Photo #11) Turnout 5

Fig. 20. (Photo #12) Gate 1

Fig. 21. (Photo #13) Gate 1 and Turnout 5

Fig. 22. (Photo #14) Turnout 6

Fig. 23. (Photo #15) Turnout 7

Fig. 24. (Photo #16) Turnout 8

Fig. 25. (Photo #17) Turnout 9

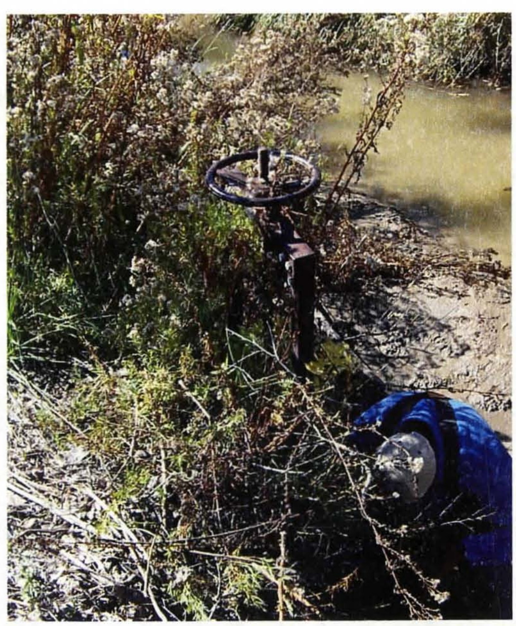

Fig. 26. (Photo #18) Turnout 10

Fig. 27. (Photo #19) Turnout 11

Fig. 28. (Photo #20) Turnout 13

Fig. 29. (Photo #21) Turnout 14

Fig. 30. (Photo #22) Turnout 16, turnout is bent over

Fig. 31. (Photo #23) Turnout 17

Fig. 32. (Photo #24) Gate 2

Fig. 33. (Photo #25) Turnout 18

Fig. 34. (Photo #26) Turnout 19

Fig. 35. (Photo #27) Turnout 20

Fig. 36. (Photo #28) Turnout 21

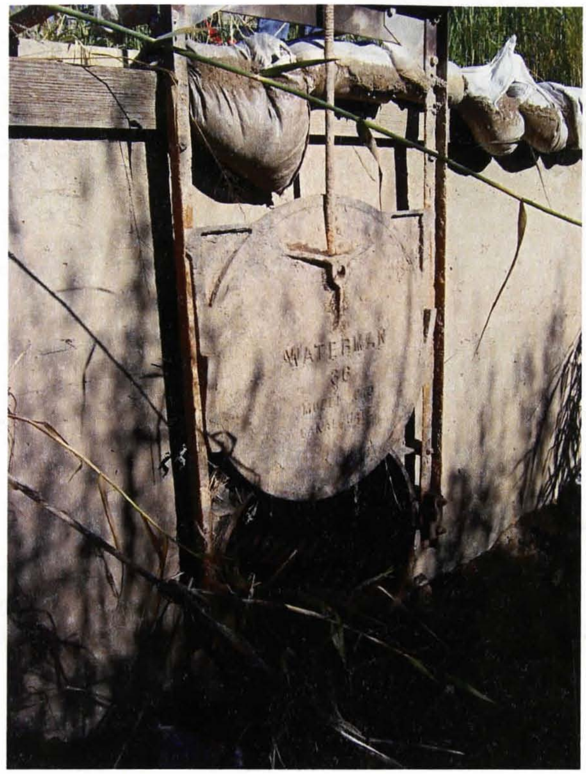

Fig. 37. (Photo #29) Return 4

Fig. 38. (Photo #30) Gate 3, not in place

Fig. 39. (Photo #31) Return 5

Fig. 40. (Photo #32) Turnout 22

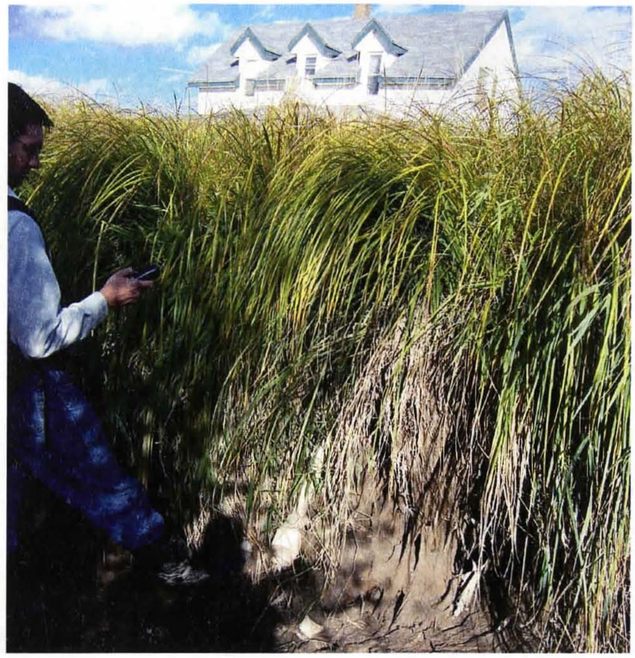

Fig. 41. (Photo #33) Residential turnout 1

Fig. 42. (Photo #34) Turnout 23

Fig. 43. (Photo #35) Turnout 24

Fig. 44. (Photo #36) Gate 4

Fig. 45. (Photo #37) Turnout 25

Fig. 46. (Photo #38) Turnout 26

Fig. 47. (Photo #39) Turnout 27

Fig. 48. (Photo #40) Residential turnout 2

Fig. 49. (Photo #41) Return 6

Fig. 50. (Photo #42) Turnout 28

Fig. 51. (Photo #43) Turnout 29

Fig. 52. (Photo #44) Turnout 30

Fig. 53. (Photo #45) Turnout 31

Fig. 54. (Photo #46) Turnout 32

Fig. 55. (Photo #47) Turnout 33

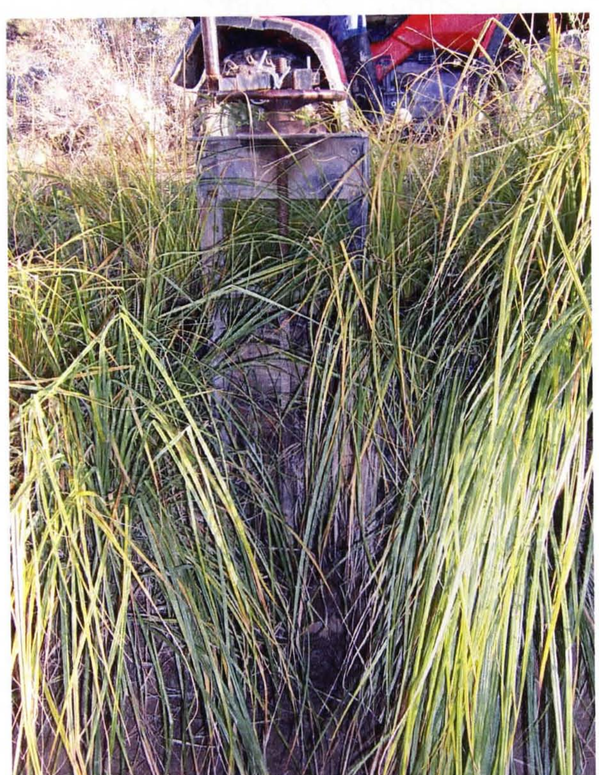

Fig. 56. (Photo #48) Turnout 34

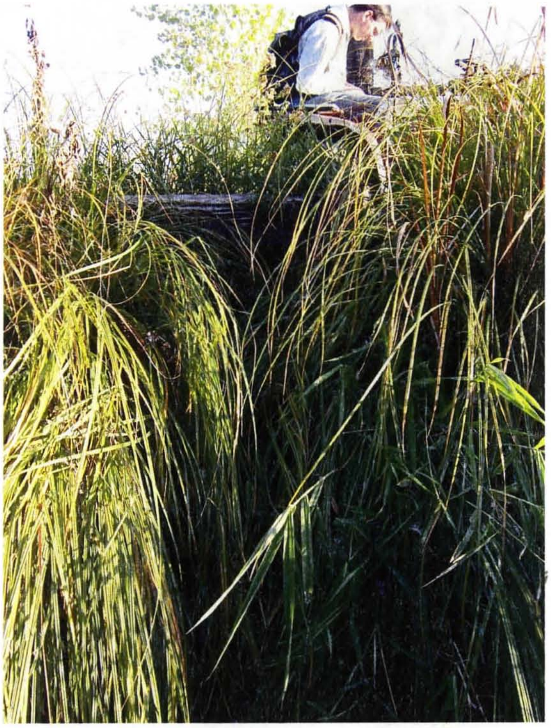

Fig. 57. (Photo #49) Turnout 35

Fig. 58. (Photo #50) Turnout 36

Fig. 59. (Photo #51) Turnout 37

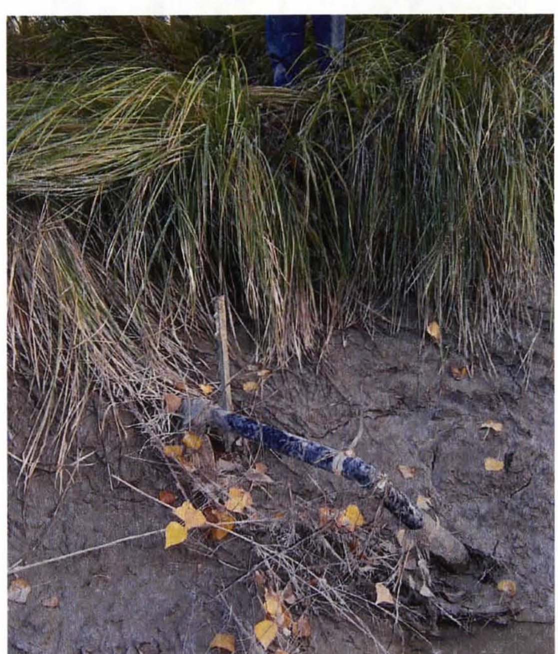

Fig. 60. (Photo #52) Residential turnout 3

Fig. 61. (Photo #53) Turnout 38

Fig. 62. (Photo #54) Turnout 39

Fig. 63. (Photo #55) Turnout 40, high school pump

Fig. 64. (Photo #56) Residential turnout 4

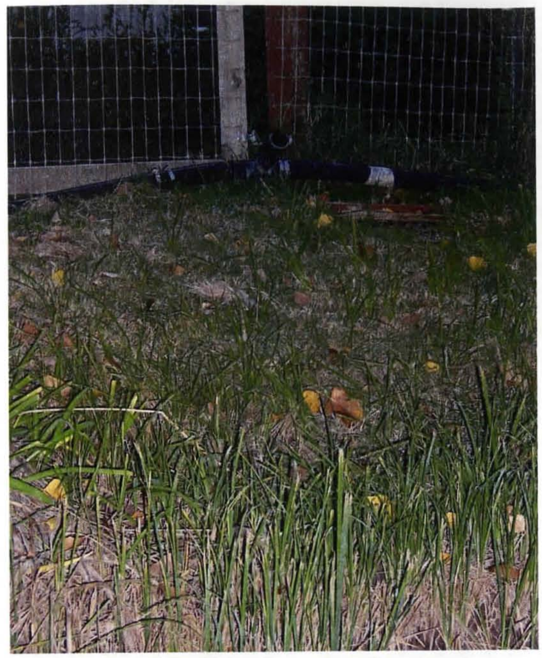

Fig. 65. (Photo #57) Residential turnout 5

Fig. 66. (Photo #58) Residential turnout 6

Fig. 67. (Photo #59) Turnout 41

Fig. 68. (Photo #60) Residential turnout 7

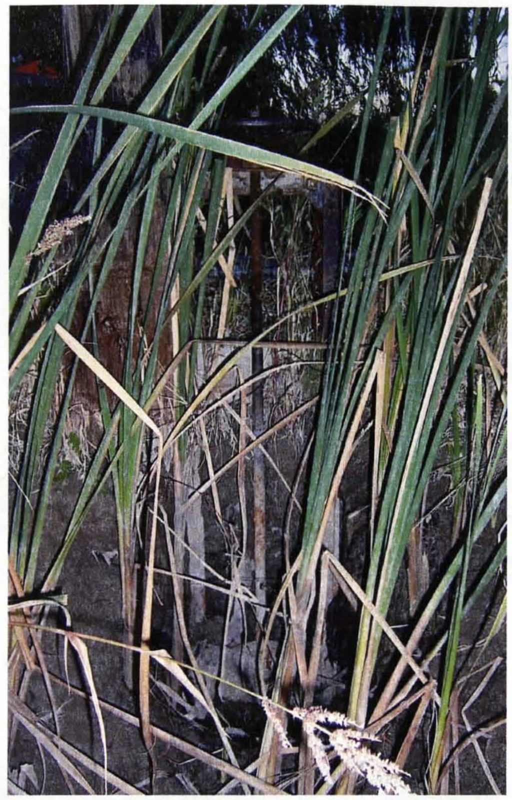

Fig. 69. (Photo #61) Turnout 42

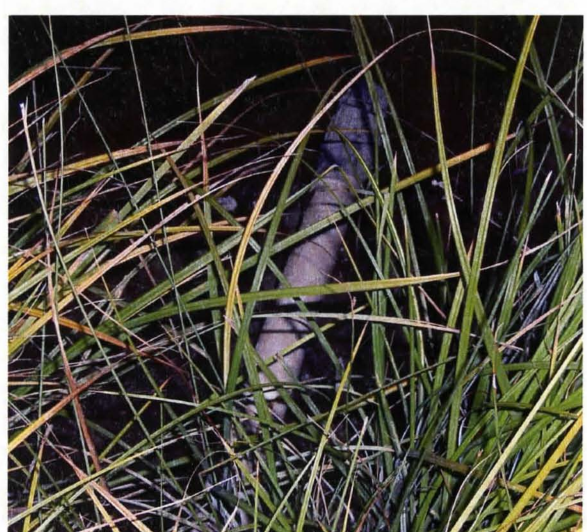

Fig. 70. (Photo #62) Residential turnout 8

Fig. 71. (Photo #63) Residential turnout 9

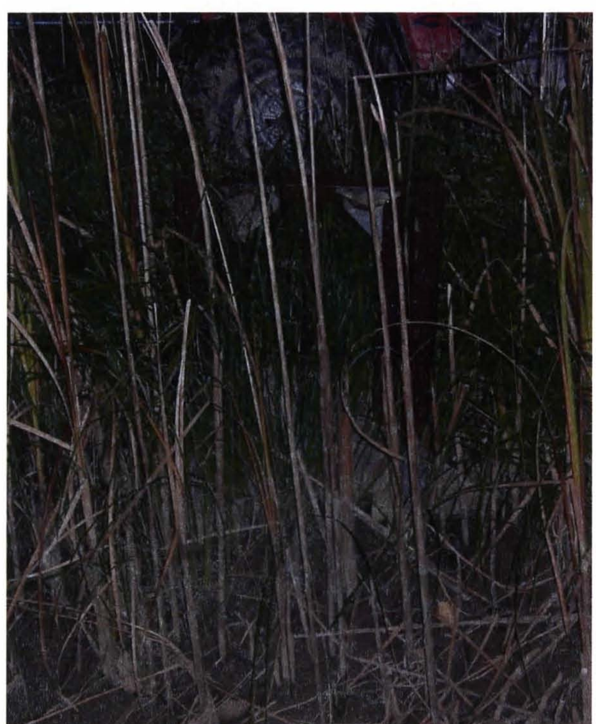

Fig. 72. (Photo #64) Turnout 43

Fig. 73. (Photo #65) Turnout 44

Fig. 74. (Photo #66) Turnout 45

Fig. 75. (Photo #67) Residential turnout 10

Fig. 76. (Photo #68) Residential turnout 11

Fig. 77. (Photo #69) Residential turnout 12

Fig. 78. (Photo #70) Gate 5

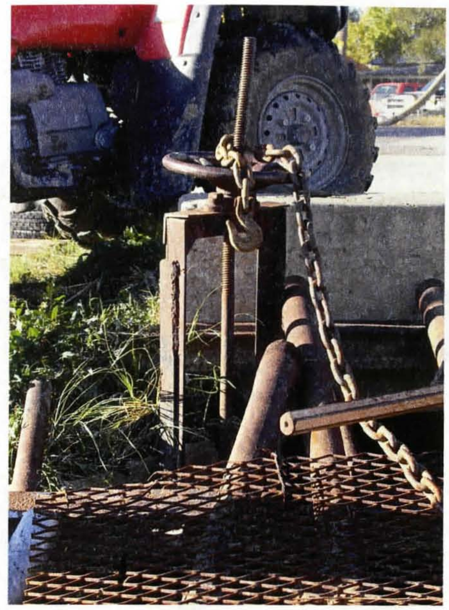

Fig. 79. (Photo #71) Turnout 46

Fig. 80. (Photo #72) Residential turnout 13

Fig. 81. (Photo #73) Residential turnout 14

Fig. 82. (Photo #74) Residential turnout 15

Fig. 83. (Photo #75) Residential turnout 16

Fig. 84. (Photo #76) Residential turnout 17

Fig. 85. (Photo #77) Residential turnout 18

Fig. 86. (Photo #78) Turnout 47

Fig. 87. (Photo #79) Residential turnout 19

Fig. 88. (Photo #80) Residential turnout 20

Fig. 89. (Photo #81) Residential turnout 21

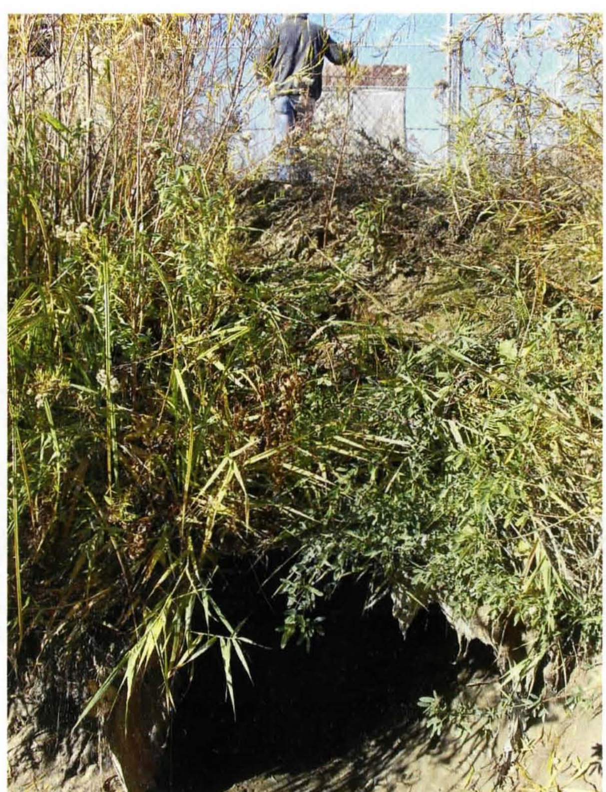

Fig. 90. (Photo #82) Turnout 48, culvert to ballpark pump

Fig. 91. (Photo #83) Turnout 48, ballpark pump

Fig. 92. (Photo #84) Residential turnout 22

Fig. 93. (Photo #85) Turnout 49

Fig. 94. (Photo #86) Turnout 49, backside

Fig. 95. (Photo #87) Turnout 50

Fig. 96. (Photo #88) Residential turnout 23

Fig. 97. (Photo #89) Turnout 51

Fig. 98. (Photo #90) Turnout 52

Fig. 99. (Photo #91) Residential turnout 24

Fig. 100. (Photo #92) Residential turnout 25

Fig. 101. (Photo #93) Residential turnout 26

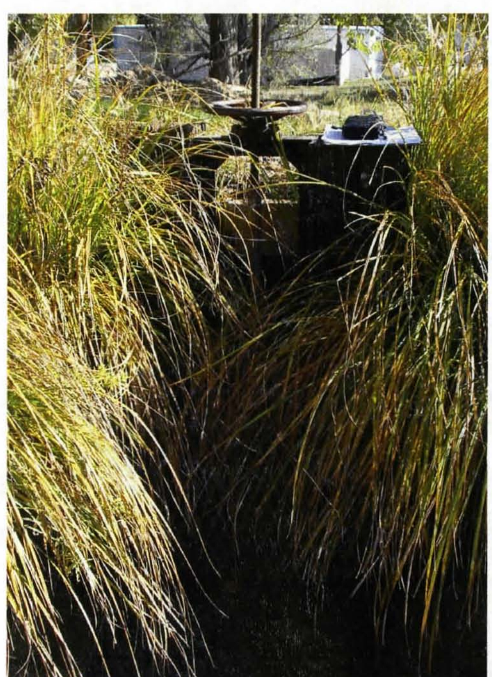

Fig. 102. (Photo #94) Turnout 53

Fig. 103. (Photo #95) Turnout 54

Fig. 104. (Photo #96) Residential turnout 27

Fig. 105. (Photo #97) Residential turnout 28

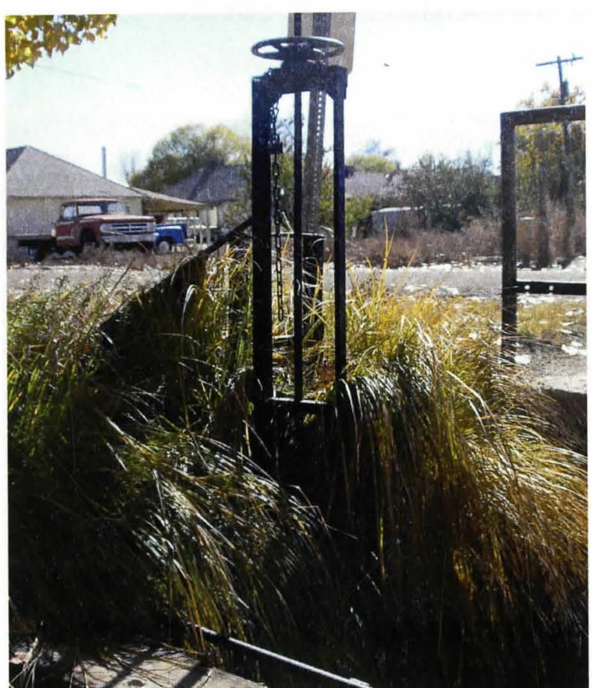

Fig. 106. (Photo #98) Turnout 55

Fig. 107. (Photo #99) Residential turnout 29

Fig. 108. (Photo #100) Residential turnout 30

Fig. 109. (Photo #101) Residential turnout 31

Fig. 110. (Photo #102) Residential turnout 32

Fig. 111. (Photo #103) Residential turnout 33

Fig. 112. (Photo #104) Turnout 56

Fig. 113. (Photo #105) Turnout 57

Fig. 114. (Photo #106) Turnout 58

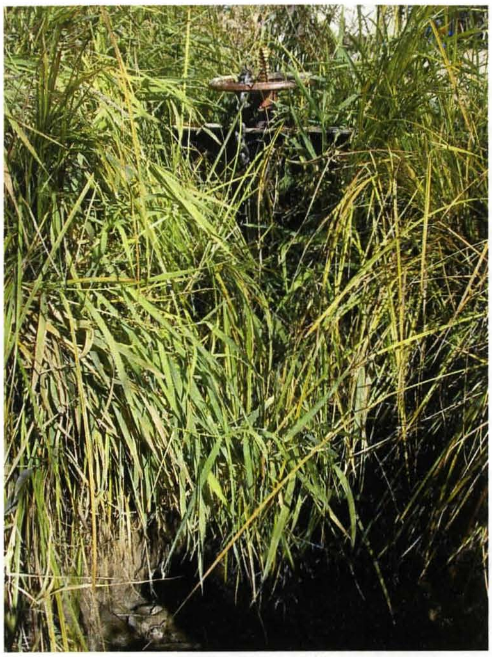

Fig. 115. (Photo #107) Turnout 59

Fig. 116. (Photo #108) Turnout 60

Fig. 117. (Photo #109) Residential turnout 34

Fig. 118. (Photo #110) Turnout 61

Fig. 119. (Photo #111) Return 7

Fig. 120. (Photo #112) Turnout 62

Fig. 121. (Photo #113) Turnout 62, backside

Fig. 122. (Photo #114) Cross section 1

Fig. 123. (Photo #115) Cross section 2

Fig. 124. (Photo #116) Cross section 3

Fig. 125. (Photo #117) Cross section 4

Fig. 126. (Photo #118) Cross section 5

Fig. 127. (Photo #119) Cross section 6

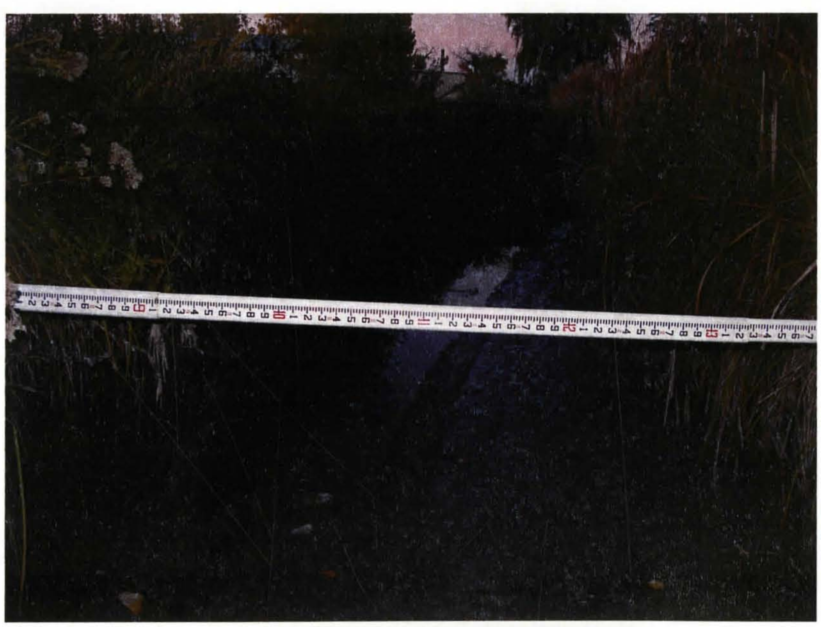

Fig. 128. (Photo #120) Cross section 7

Fig. 129. (Photo #121) Cross section 8